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CARBON DIOXIDE RELEASE FROM THE SOIL DURING RESIDUE DECOMPOSITION

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INTRODUCTION

Soil bacteria and fungi drive most of the biogeochemical processes in agricultural soils (Paul and Voroney, 1980). Soil microorganisms impact agroecosystem productivity by regulating nutrient cycling and availability, determining soil carbon storage, and contributing to atmospheric carbon dioxide (CO_2). The soil near the surface is the most biologically active. Upper soil levels undergo greater diurnal and seasonal changes in temperature and moisture than the underlying soil, and are exposed to the largest fertilizer and residue inputs. These factors have a considerable influence on the populations and activities of soil microorganisms (Paul and Clark, 1989).

Most management practices, such as tillage or addition of crop residues, affect the activity of soil microorganisms. Residue decomposition in agroecosystems is an important process in the cycling of essential nutrients. Residue decomposition is a result of metabolic activity by soil organisms, with the accompanying production of CO_2. Biological decomposition is often characterized as a three phase process. In the relatively rapid initial phase, the readily utilizable compounds, such as sugars, amino acids, and organic acids, are oxidized. The decomposition process slows during the second phase as the more resistant materials, cellulose and hemicellulose, are attacked by the soil microorganisms. In the third, and slowest, phase the decomposition of the very resistant components, such as lignin, takes place (Tietema, 1993). Some residue or residue decomposition products might be lost by soil erosion or by water leaching through the soil profile (Joergensen and Meyer, 1990).

Carbon dioxide efflux measurements are regularly used in carbon cycling studies in terrestrial ecosystems. They provide data that are indices of rates of organic matter decomposition. The CO_2 efflux data are normally expressed per unit soil surface area or mass. In early laboratory studies Waksman and Starkey (1924) measured CO_2 evolution from soil samples to use as indices of soil fertility. Oxygen uptake by soil samples, determined by the Warburg manometric method, might also be used to estimate the decomposition process (Rovira, 1953). There has recently been an increased interest, aided by the development of various types of analytical equipment, in the use of CO_2 evolution measurements to assess soil microbial activity.

Factors such as residue additions, tillage, fertilization, and climate, have been intensively investigated to evaluate their effects on crop growth or productivity. However, surprisingly little work has been done to investigate their effect on the activity or population dynamics of soil microorganisms. In addition, there is increasing interest in the importance of agroecosystems in the global carbon balance, especially their role as either a source or sink for CO_2 under varying climatic conditions. This study was started to gain a better understanding of microbial activity, and CO_2 production, during residue decomposition in soils and climatic conditions of the inland Pacific Northwest.

MATERIALS AND METHODS

The study was conducted on a Walla Walla silt loam soil at the Columbia Plateau Conservation Research Center, located 9 miles northeast of Pendleton, OR. The center is about 1,500 feet above sea level and has annual precipitation of 12 to 16 inches. Soil samples were collected from the upper 3 inches in essentially level fields. Soils used to estimate basal soil respiration and substrate induced respiration were collected from a fallow field. Residue and plant roots were removed from these samples. Samples used to estimate residue amended respiration came from a field that had been harvested with a stripper-header and had 7,500 pounds of residue per acre (Wilkins, personal communication). Actively growing plant roots were also excluded from these samples. Soil moisture on all samples was determined gravimetrically.

Basal soil CO_2 respiration was estimated by placing approximately 10 g of nonamended soil in gas-tight 70 mL bottles. The sample bottles were buried in the soil, which allowed incubation at the prevailing soil temperature. Soil microbial biomass carbon was estimated by the substrate induced respiration method (Anderson and Domsch, 1978). Forty milligrams of glucose in aqueous solution was added to approximately 10 g of nonamended soil in 70 mL gas-tight bottles and the amended soil samples were incubated at soil temperature in the field. Estimation of the CO_2 respiration from residue amended soil was determined by adding approximately 130 g of residue containing soil to a gas-tight 1,000 mL bottle. The larger volume bottle allowed inclusion of the residue with a minimum disruption of the sample. Sample bottles were also placed in the soil for incubation.

Carbon dioxide production was determined with a Beckman infrared gas analyzer (Clegg et al, 1978). The CO_2 concentration was measured four times over a 90-minute period, and the rate of CO_2 production derived from linear regression analysis. Soil respiration rate per gram of soil (μg CO_2/g dry soil/hour) at each date was calculated as the mean of four measurements. Soil microbial biomass was computed from the substrate induced respiration rate as proposed by Kaiser et al. (1992). The distribution of sample means were calculated using standard statistical methods (Little and Hills, 1972).

RESULTS AND DISCUSSION

Soil temperatures at 1 inch were generally greater than at the 4 inch depth (Figure 1). Ambient air temperatures are also shown for reference. The largest temperature difference between depths occurred in June where the temperature at 1 inch was

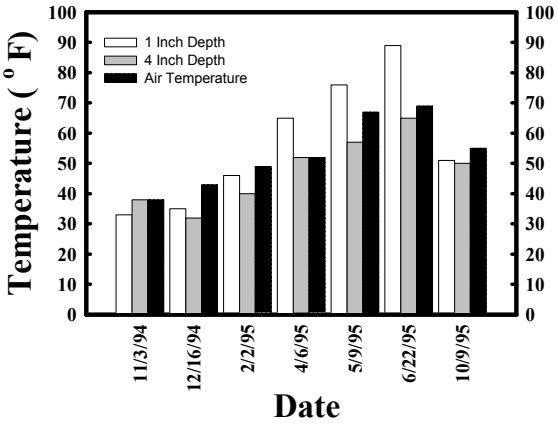

Figure 1. Soil Temperature. Bars are the hourly averages (11:00 AM to 1:00 PM) during the incubation time of the respiration measurements. Pendleton, OR.

1.36 times greater than the temperature at 4 inches, almost 90 °F and 65 °F, respectively. Soil temperatures remained above freezing on sampling dates and, thus, did not restrict the soil sampling procedures.

Overall soil moisture content was good; the soil was never extremely dry at any sampling date (Figure 2). Seasonal

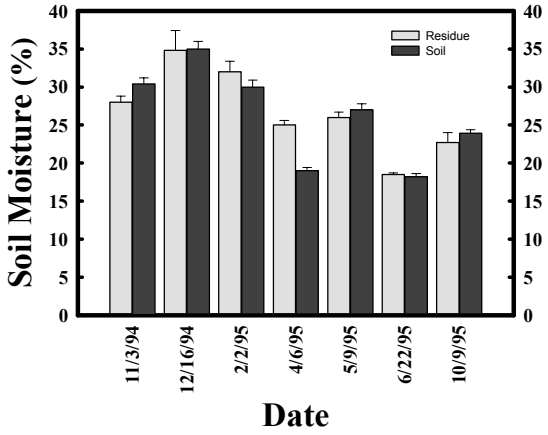

Figure 2. Soil Moisture Content. Bars are the means of gravimetric soil moisture measurements. Error bars are the standard error of the mean. Pendleton, OR.

variations in soil moisture content reflect the typical rainfall patterns in the inland Pacific Northwest, where cool wet winters and warm dry summers prevail. Precipitation in early May (1.56 inches from 5/1 to 5/9) and June (1.73 inches from 6/1 to 6/20) accounts for the relatively high levels of soil moisture found on the May and June sampling dates. Soil aeration is generally controlled by soil moisture; however, even at the greatest soil moisture content, it is unlikely that the top 4 inches of the soil was anaerobic.

Soil respiration was very low in the late fall and winter months, and increased in the spring, with peak activity in April and early May. Soil respiration declined in late June and October (Figure 3). Soil respiration remained detectable throughout

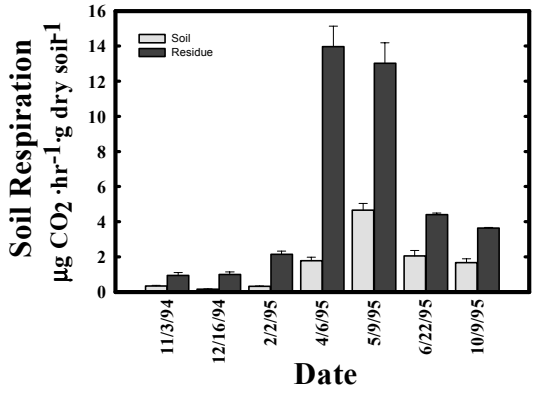

Figure 3. Soil Respiration. Bars are the means of CO_2 efflux from the soil. Error bars are the standard error of the mean. Soil bars are unamended soil, residue bars are soil amended with residue. Pendleton, OR.

the experiment, even when temperatures were almost at the freezing point in December and February. Overall, respiration was positively correlated with soil temperature, but showed little correlation to soil water content. These findings were similar to those of Alvarez and coworkers (1995). Koizumi and coworkers (1993) have suggested that temperature, not soil moisture, has the greatest effect on soil respiration in temperate climates and our findings support this hypothesis. The addition of residue greatly increased soil respiration, and the difference in amended and nonamended respiration was greatest during the winter. Residue amended soils had 10 and 18 percent greater respiration than the unamended soils in December and February respectively (Figure 3).

Comparisons between different techniques for measuring soil CO_2 efflux have shown that some bias is associated with all of them (De Jong et al, 1979). The

amount of bias might reflect the amount of disturbance to the local environment caused by each method. The static type incubation technique used in this study might overestimate soil respiration. During the sampling procedure, sections of the soil are exposed to the air. In addition, cracks and fissures develop in the soil sample, which might increase the soil oxygen concentration and thus increase respiration. However, this method eliminates actively metabolizing root tissue that would contribute CO_2 and produce an over estimation of soil respiration. Allison and Killham (1988) have shown that the incorporation of plant residues produces a rapid proliferation of soil microorganisms. Initially, they are predominantly young cells, which give a higher CO_2 production per unit biomass (Anderson and Domsch, 1978), and might cause the overestimation of microbial carbon after recent addition of residue.

The carbon content in the soil microbial biomass (Figure 4), estimated by the substrate induced respiration method, is an indication of the population of metabolically active microorganisms in the soil at a given time. The seasonal variation in the microbial population, with low values in the winter, increasing through the spring then declining into summer and fall; was affected by soil temperature. The linkage of microbial biomass with temperature is consistent with the findings of others (Lynch and Panting, 1980; Ocio and Brookes, 1990). However, we observed a decline in microbial biomass in June when the soil temperature remains elevated. As the soil moisture was probably adequate for microbial activity, we propose that the reduction in biomass might be the result of the relatively high soil temperatures inhibiting microbial metabolisms, thus producing a decline in their populations.

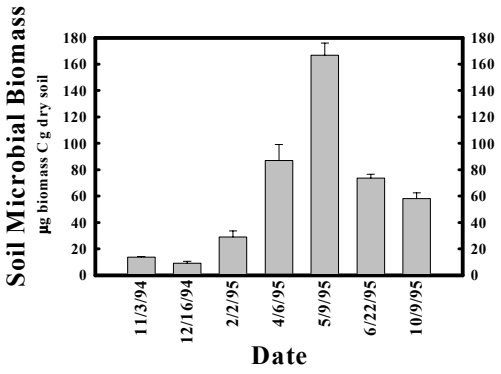

Figure 4. Soil Microbial Biomass. Bars are the means of four measurements. Error bars are the standard error of the mean. Pendleton, OR.

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